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Yuya HASEGAWA et al. :

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VERIFICATION OF ENGLISH TRANSLATION

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

I, Nobuyoshi MITANI, declare that I am conversant in both the Japanese and English languages and that the English translation as attached hereto is an accurate translation of Japanese Patent Application No. 2002-342760 filed on November 26, 2002.

Signed this 19 th day of May, 2006

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PATENT OFFICE

JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy of the following application as filed with this Office.

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TITLE OF THE INVENTION: ACTUATOR

CLAIMS:

1. An actuator comprising:

a stationary member which has a coil;

a casing for accommodating the stationary member; and

a movable member which has a shaft and is supported by the casing so as to be moved in an axial direction of the shaft and in a rotational direction having the shaft as its rotational axis;

wherein electric current is caused to flow through the coil so as to move the movable member in the axial direction and in the rotational direction;

wherein the movable member has a magnet having a magnetization direction substantially orthogonal to the axial direction;

wherein the stationary member includes a first stationary member for imparting to the movable member by the magnet a force oriented in the axial direction and a second stationary member for imparting to the movable member by the magnet a force oriented in the rotational direction;

wherein the coil includes a first coil for exciting a magnetic path passing through the first stationary member and a second coil for exciting a magnetic path passing through the second stationary member.

2. The actuator as claimed in Claim 1, wherein the magnet of the movable member is disposed symmetrically with respect to the rotational axis.

3. The actuator as claimed in Claim 1 or 2, wherein a pair of the first stationary members are provided symmetrically with respect to the rotational axis and a pair of the second stationary members are provided symmetrically with

respect to the rotational axis;

wherein the first coil excites the pair of the first stationary members in an antiphase mode and the second coil excites the pair of the second stationary members in an antiphase mode.

4. The actuator as claimed in Claim 3, wherein the pair of the first stationary members and the pair of the second stationary members are provided such that a plane containing the pair of the first stationary members and a plane containing the pair of the second stationary members intersect with each other substantially orthogonally.

5. The actuator as claimed in Claims 1 to 4, wherein the movable member has two magnets having opposite magnetization directions, respectively and the first stationary member is formed by a substantially E-shaped magnetic part having three magnetic pole portions arranged in the axial direction.

6. The actuator as claimed in Claim 5, wherein the second stationary member is formed by a substantially C-shaped magnetic part having two magnetic pole portions arranged in the axial direction.

7. The actuator as claimed in Claim 6, wherein end portions of the magnetic pole portions of the first stationary member and end portions of the magnetic pole portions of the second stationary member overlap each other in three directions.

8. The actuator as claimed in Claim 7, wherein a gap is defined between each of the magnetic pole portions of the first stationary member and each of the magnetic pole portions of the second stationary member.

9. The actuator as claimed in Claim 6, wherein an end portion of each of the magnets of the movable member is operated so as to traverse each of two

recesses of the first stationary member.

10. The actuator as claimed in Claim 6, wherein the magnets of the movable member are formed into an identical size such that not only opposed end faces of the magnets are brought into contact with each other but other end faces of the magnets remote from the contacting opposed end faces are flush with axial opposite end faces of the first stationary member.

11. The actuator as claimed in Claim 6, wherein the first and second coils are dividedly wound around the first and second stationary members, respectively.

12. The actuator as claimed in Claims 1 to 11, further comprising:

an axial resonant spring for exerting an action on motion in the axial direction, which is provided between the movable member and the casing.

13. The actuator as claimed in Claim 12, further comprising:

a rotational resonant spring for exerting an action on motion in the rotational direction, which is provided between movable member and the casing.

14. The actuator as claimed in Claim 13, wherein a single spring member functions as both of the axial resonant spring and the rotational resonant spring.

DETAILED DESCRIPTION OF THE INVENTION:

[0001]

[Technical Field of the Invention]

The present invention relates to an actuator which is capable of moving in two directions of an axial direction and a rotational direction.

[0002]

[Prior Art]

Many actuators are adapted to move in one direction of a linear direction or a rotational direction. When an actuator is moved in two directions of the linear direction and the rotational direction, a motion direction converting mechanism for converting a motion direction mechanically is employed. However, the motion direction converting mechanism produces noises when converting the motion direction.

[0003]

Japanese Patent Laid-Open Publication No. 2002-78310 discloses, in a linear actuator in which a movable member (plunger) having a shaft is disposed inside a stationary member (yoke) so as to have a gap with the stationary member and a magnetic path is excited by a coil such that the movable member is moved in an axial direction of the shaft, an arrangement in which by making the gap nonuniform relative to axial displacement (stroke position) of the movable member, the movable member is moved in an axial direction of the shaft, i.e., in a linear direction and in a rotational direction having the shaft as its rotational axis without using the motion direction converting mechanism.

[0004]

[Patent document 1]

Japanese Patent Laid-Open Publication No. 2002-78310

[0005]

[Problems to be solved by the Invention]

However, although the arrangement disclosed in Japanese Patent Laid-Open Publication No. 2002-78310 is useful in that the movable member can be moved in the two directions in response to axial displacement of the movable member in a simple construction without using the motion direction converting

mechanism presenting a cause of noises, relation between motion of the movable member in the axial direction and the motion of the movable member in the rotational direction is fixed by shape of the gap, so that the motion of the movable member in the axial direction and the motion of the movable member in the rotational direction cannot be controlled independently of each other and thus, degree of freedom of operational control of the movable member is not so high.

[0006]

With a view to eliminating the above mentioned drawbacks of prior art, the present invention has for its object to upgrade degree of freedom of operational control of an actuator which is capable of moving in two directions of an axial direction and a rotational direction without using a motion direction converting mechanism.

[0007]

[Means for solving the Problems]

An actuator of Claim 1 comprises: a stationary member which has a coil; a casing for accommodating the stationary member; and a movable member which has a shaft and is supported by the casing so as to be moved in an axial direction of the shaft and in a rotational direction having the shaft as its rotational axis; wherein electric current is caused to flow through the coil so as to move the movable member in the axial direction and in the rotational direction; wherein the movable member has a magnet having a magnetization direction substantially orthogonal to the axial direction; wherein the stationary member includes a first stationary member for imparting to the movable member by the magnet a force oriented in the axial direction and a second stationary member for imparting to the movable member by the magnet a force oriented in the rotational direction;

wherein the coil includes a first coil for exciting a magnetic path passing through the first stationary member and a second coil for exciting a magnetic path passing through the second stationary member.

[0008]

Therefore, since the first stationary imparts to the movable member the force oriented in the axial direction when the first coil excites the magnetic path passing through the first stationary member, while the second stationary member imparts to the movable member the force oriented in the rotational direction when the second coil excites the magnetic path passing through the second stationary member, motions of the movable member in the axial direction and in the rotational direction can be controlled independently of each other. As a result, it is possible to upgrade degree of freedom of operational control of the actuator which is capable of moving in two directions of the axial direction and the rotational direction without using a motion direction converting mechanism.

[0009]

In Claim 2, the magnet of the movable member is disposed symmetrically with respect to the rotational axis in the actuator of Claim 1.

[0010]

Therefore, since mass of the magnet of the movable member is distributed symmetrically with respect to the rotational axis, inertia force based on motion of the movable member in the rotational direction is cancelled, so that vibrations transmitted to the casing can be lessened.

[0011]

In Claim 3, a pair of the first stationary members are provided symmetrically with respect to the rotational axis and a pair of the second

stationary members are provided symmetrically with respect to the rotational axis, while the first coil excites the pair of the first stationary members in an antiphase mode and the second coil excites the pair of the second stationary members in an antiphase mode in the actuator of Claim 1 or 2.

[0012]

Therefore, since the first and second stationary members impart, by using opposite magnetic poles of the magnet of the movable member, to the movable members the force oriented in the axial direction and the force oriented in the rotational direction, the movable member can be moved with great force.

[0013]

In Claim 4, the pair of the first stationary members and the pair of the second stationary members are provided such that a plane containing the pair of the first stationary members and a plane containing the pair of the second stationary members intersect with each other substantially orthogonally in the actuator of Claim 3.

[0014]

Therefore, since an interval between the first and second stationary members becomes large, a space for providing the first and second coils can be enlarged.

[0015]

In Claim 5, the movable member has two magnets having opposite magnetization directions, respectively and the first stationary member is formed by a substantially E-shaped magnetic part having three magnetic pole portions arranged in the axial direction in the actuator of Claims 1 to 4.

[0016]

Therefore, when the two magnets are disposed so as to confront the first stationary member, the magnetic pole portions of the first stationary member are disposed at positions suitable for producing a force oriented in the axial direction. Thus, leakage flux is lessened and the movable member can be efficiently moved in the axial direction with great force.

[0017]

In Claim 6, the second stationary member is formed by a substantially C-shaped magnetic part having two magnetic pole portions arranged in the axial direction in the actuator of Claim 5.

[0018]

Therefore, when the two magnets are disposed so as to confront the two magnetic pole portions of the second stationary member, the magnetic pole portions of the second stationary member are disposed at positions suitable for producing a force oriented in the rotational direction. Thus, leakage flux is lessened and the movable member can be efficiently moved in the rotational direction with great force.

[0019]

In Claim 7, end portions of the magnetic pole portions of the first stationary member and end portions of the magnetic pole portions of the second stationary member overlap each other in three directions in the actuator of Claim 6.

[0020]

Therefore, since a space covering an area for confronting the first stationary member with the movable member and a space covering an area for confronting the second stationary member with the movable member are secured,

the area for confronting the first stationary member with the movable member and the area for confronting the second stationary member with the movable member can be increased, so that a large force can be applied to the movable member.

[0021]

In Claim 8, a gap is defined between each of the magnetic pole portions of the first stationary member and each of the magnetic pole portions of the second stationary member in the actuator of Claim 7.

[0022]

Therefore, since a magnetic reluctance of a magnetic path between the first stationary member and the second stationary member is increased, a magnetic flux which does not contribute to application of a force to the movable member can be reduced.

[0023]

In Claim 9, an end portion of each of the magnets of the movable member is operated so as to traverse each of two recesses of the first stationary member in the actuator of Claim 6.

[0024]

Therefore, since an area for confronting a magnetic pole portion of each of the magnets with each of the magnetic pole portions of the first stationary member can be increased, the movable member can be moved in the axial direction with great force.

[0025]

In Claim 10, the magnets of the movable member are formed into an identical size such that not only opposed end faces of the magnets are brought into contact with each other but other end faces of the magnets remote from the

contacting opposed end faces are flush with axial opposite end faces of the first stationary member in the actuator of Claim 6.

[0026]

Therefore, a position where the other end faces of the magnets are flush with the axial opposite end faces of the first stationary member presents a stable point. Thus, as axial displacement of the movable member becomes larger, a larger force is applied to the movable member in a direction opposite to that of the axial displacement, so that effect of a return spring can be gained.

[0027]

In Claim 11, the first and second coils are dividedly wound around the first and second stationary members, respectively in the actuator of Claim 6.

[0028]

Therefore, by dividing the coils, an influence of a thickness of the wound coils is lessened in comparison with a case in which the coils are wound around one location, so that a space for winding the coils can be reduced.

[0029]

In Claim 12, the actuator of Claims 1 to 11 further comprises: an axial resonant spring for exerting an action on motion in the axial direction, which is provided between the movable member and the casing.

[0030]

Therefore, when an AC voltage is applied to the first coil at a frequency close to a resonant frequency determined by a mass of the movable member and a spring constant of the axial resonant spring, the movable member can be efficiently reciprocated in the axial direction at a large amplitude on the basis of a resonance phenomenon.

[0031]

In Claim 13, the actuator of Claim 12 further comprises: a rotational resonant spring for exerting an action on motion in the rotational direction, which is provided between movable member and the casing.

[0032]

Therefore, when an AC voltage is applied to the second coil at a frequency close to a resonant frequency determined by a moment of inertia of the movable member and a spring constant of the rotational resonant spring, the movable member can be efficiently reciprocated in the rotational direction at a large amplitude on the basis of a resonance phenomenon.

[0033]

In Claim 14, a single spring member functions as both of the axial resonant spring and the rotational resonant spring in the actuator of Claim 13.

[0034]

Therefore, since the axial resonant spring and the rotational resonant spring are formed by the single spring member, a space for providing the axial resonant spring and the rotational resonant spring can be reduced.

[0035]

[Embodiments of the Invention]

(First embodiment)

Hereinafter, a first embodiment of the present invention directed to Claims 1 to 6 and 11 is described with reference to Figs. 1 to 9. The first embodiment includes a casing 1, a first stationary member 2, a first coil 3, a second stationary member 4, a second coil 5 and a movable member 6 as its main constituent elements.

[0036]

The casing 1 is formed by a housing portion 1a and a bearing portion 1b. The housing portion 1a is formed by metallic magnetic material into a cylindrical shape having a closed bottom, while the bearing portion 1b is provided at a central portion of each of opposite end faces of the housing portion 1a. The casing 1 accommodates the first stationary member 2, the first coil 3, the second stationary member 4, the second coil 5 and the movable member 6. The bearing portion 1b is formed into a sectional shape of a concentric hollow column so as to act as a bearing in which metal balls each having a smoothly worked surface are filled into the hollow. The bearing portion 1b is provided at each of the opposite end faces of the housing portion 1a such that a central axis of the housing portion 1a coincides with that of the bearing portion 1b. These bearing portions 1b can support a cylindrical shaft by the metal balls so as to move the shaft in its axial direction (hereinafter, referred to as an "axial direction") and in a rotational direction (hereinafter, referred to as a "rotational direction") having the axial direction as its central axis (hereinafter, referred to as a "rotational axis").

[0037]

The first stationary member 2 is formed by magnetic material into an E-shaped column in section and has three E-shaped magnetic pole portions arranged in the axial direction. A pair of the first stationary members 2 are mounted and accommodated in a hollow of the housing portion 1a of the casing 1 symmetrically with respect to the rotational axis. The three E-shaped magnetic pole portions are formed symmetrically and have an identical width and an identical length. The first coil 3 is wound around the central magnetic pole portion and different magnetic poles are produced at the central magnetic pole

portion and the opposite magnetic pole portions by causing electric current to flow through the first coil 3. For example, if an S-pole is produced at the central magnetic pole portion, an N-pole is produced at the opposite magnetic pole portions. Since these magnetic pole portions are disposed so as to confront the movable member 6, an efficient magnetic circuit in which leakage flux is small is formed. The first stationary members 2 are mainly used for applying to the movable member 6 a force oriented in the axial direction.

[0038]

The first coil 3 is wound around the central magnetic pole portion of the first stationary member 2 via a resinous coil bobbin (not shown). The first coil 3 is adapted to excite a magnetic path passing through the first stationary member 2, a gap and the movable member 6. By causing electric current to flow through the first coil 3, different magnetic poles are produced at the central magnetic pole portion and the opposite magnetic pole portions. Meanwhile, the first coil 3 provided in one of the two stationary members 2 and the first coil 3 provided in the other first stationary member 2 are connected to each other so as to perform excitation in an antiphase mode. For example, when the central magnetic pole portion of the one first stationary member 2 is excited to an S-pole, the central magnetic pole portion of the other first stationary member 2 is excited to an N-pole upon connection of the two first coils 3.

[0039]

The second stationary member 4 is formed by magnetic material into a C-shaped column in section and has two C-shaped magnetic pole portions arranged in the axial direction. A pair of the second stationary members 4 are mounted and accommodated in the hollow of the housing portion 1a of the casing

1 symmetrically with respect to the rotational axis. A plane containing the first stationary members 2 and a plane containing the second stationary members 4 intersect with each other orthogonally. Hence, since an interval between the first stationary member 2 and the second stationary member 4 becomes large, a space for providing the first coil 3 and the second coil 5 can be made large. The two C-shaped magnetic pole portions of the second stationary member 4 are formed symmetrically and have an identical width and an identical length. The two second coils 5 are, respectively, wound around the opposite magnetic pole portions dividedly and different magnetic poles are, respectively, produced at the opposite magnetic pole portions by causing electric current to flow through the two second coils 5. For example, if an S-pole is produced at one of the two magnetic pole portions, an N-pole is produced at the other magnetic pole portion. Since the opposite magnetic pole portions are disposed so as to confront the movable member 6, an efficient magnetic circuit in which leakage flux is small is formed. The second stationary members 4 are mainly used for applying to the movable member 6 a force oriented in the rotational direction.

[0040]

The two second coils 5 are, respectively, wound around the opposite magnetic pole portions of the second stationary member 4 dividedly by way of a resinous coil bobbin (not shown). The second coil 5 is adapted to excite a magnetic path passing through the second stationary member 4, a gap and the movable member 6. By causing electric current to pass through the second coils 5, different magnetic poles are, respectively, produced at the opposite magnetic pole portions of the second stationary member 4. Meanwhile, one of the second coils 5 provided in one of the two second stationary member 4 and a

corresponding one of the second coils 5 provided in the other second stationary member 4 are connected to each other so as to perform excitation in an antiphase mode. For example, when one of the opposite magnetic pole portions of one second stationary member 4 is excited to an S-pole, a corresponding one of the opposite magnetic pole portions of the other second stationary member 4 is excited to an N-pole.

[0041]

The movable member 6 is formed by a shaft 6a and a driving force generator 6b. The shaft 6a is formed by a metallic cylinder and is supported by the two bearing portions 1b so as to be moved in the axial direction and in the rotational direction. The driving force generator 6b is formed by two cylindrical magnets 6ba and 6bb magnetized radially such that a magnetization direction oriented towards an N-pole from an S-pole in the magnet 6ba is opposite to that of the magnet 6bb. The magnets 6ba and 6bb are mounted on the shaft 6a such that a central axis of the magnets 6ba and 6bb coincides with that of the shaft 6a. Thus, the magnets 6ba and 6bb are provided symmetrically with respect to the rotational axis such that the magnetization directions of the magnets 6ba and 6bb intersect with the axial direction orthogonally. Therefore, since masses of the magnets 6ba and 6bb are distributed symmetrically with respect to the rotational axis, inertia force based on motion of the movable member 6 in the rotational direction is cancelled and thus, vibrations to be transmitted to the casing 1 can be reduced. Meanwhile, since the first stationary members 2 and the second stationary members 4 apply to the movable member 6 the force oriented in the axial direction and the force oriented in the rotational direction by using the magnetic poles disposed at opposite sides of the magnets 6ba and 6bb of the

movable member 6, the movable member 6 can be moved with great force. Each of the magnets 6ba and 6bb has a thickness equal to a width of each of two recesses of the E-shaped first stationary member 2. The magnets 6ba and 6bb are provided at such an interval on the shaft 6a that side faces of the magnets 6ba and 6bb confront the two recesses of the first stationary member 2, respectively. At this time, the magnets 6ba and 6bb confront the magnetic pole portions of the second stationary member 4, respectively. A diameter of the magnets 6ba and 6bb is determined such that a gap is defined between the driving force generator 6b and the first stationary member 2 and between the driving force generator 6b and the second stationary member 4.

[0042]

By causing electric current to pass through the first coil 3 in the above described arrangement, magnetic poles shown in, for example, Fig. 2 are produced in the magnetic pole portions of the first stationary member 2. Then, the magnet 6ba undergoes an attraction force from the uppermost magnetic pole portion of the first stationary member 2 and a repulsion force from the central magnetic pole portion of the first stationary member 2. On the other hand, the magnet 6bb undergoes an attraction force from the central magnetic pole portion of the first stationary member 2 and a repulsion force from the lowermost magnetic pole portion of the first stationary member 2. Therefore, the movable member 6 undergoes from the first stationary member 2 a force oriented in the axial direction, i.e., in the upward direction in Fig. 2. If electric current is caused to flow through the first coil 3 in a direction opposite to that of the above, polarities of magnetic poles produced in the magnetic pole portions become opposite to those of the above, so that the movable member 6 undergoes a force oriented in

the opposite axial direction.

[0043]

Meanwhile, by causing electric current to pass through the second coil 5, magnetic poles shown in, for example, Fig. 4 are produced in the magnetic pole portions of the second stationary member 4. Thus, since the magnet 6ba undergoes a force mainly from the second stationary member 4, the magnet 6ba undergoes a force oriented in the clockwise rotational direction. Meanwhile, since the magnet 6bb also undergoes a force mainly from the second stationary member 4, the magnet 6bb undergoes a force oriented in the clockwise rotational direction. Therefore, the movable member 6 undergoes from the second stationary member 4 the force oriented in the rotational direction, i.e., in the clockwise rotational direction in Fig. 4. Meanwhile, if electric current is caused to flow through the second coil 5 in a direction opposite to that of the above, polarities of magnetic poles produced in the magnetic pole portions of the second stationary member 4 become opposite to those of the above, so that the movable member 6 undergoes a force oriented in the opposite rotational direction.

[0044]

Therefore, since the axial direction and the rotational direction of the movable member 6 can be controlled independently of each other in this actuator, the actuator has thrust characteristics relative to axial displacement and torque characteristics relative to rotational angle in the rotational direction as shown in Fig. 5. Namely, when electric current does not flow through the first coil 3, electric current flows through the first coil 3 in a plus direction and electric current flows through the first coil 3 in a minus direction, thrust characteristics shown by curves FZ1, FP1 and FM1, respectively are obtained. Meanwhile, when electric current

does not flow through the second coil 5, electric current flows through the second coil 5 in a plus direction and electric current flows through the second coil 5 in a minus direction, torque characteristics shown by curves TZ1, TP1 and TM1, respectively are obtained. Here, a positional relation in which the first stationary member 2 and the movable member 6 are disposed as shown in Fig. 2 is employed as a reference position of the thrust characteristics. Meanwhile, a positional relation in which the first stationary members 2, the second stationary members 4 and the movable member 6 are disposed as shown in Fig. 4 is employed as a reference position of the torque characteristics. Therefore, if an AC voltage is applied to the first coil 3 and the second coil 5, electric current flows through the first coil 3 and the second coil 5 in the plus direction and the minus direction, respectively, so that the movable member 6 is reciprocated in two directions of the axial direction and the rotational direction.

[0045]

Meanwhile, if the second stationary member 4 is formed into an E-shaped configuration as shown in Fig. 6 in the same manner as the first stationary member 2, positional relation between the magnet 6ba and an uppermost magnetic pole portion of the second stationary member 4 in Fig. 7 generates a force for performing clockwise rotation of the magnet 6ba, while positional relation between the magnet 6bb and a lowermost magnetic pole portion of the second stationary member 4 in Fig. 7 generates a force for performing counterclockwise rotation of the magnet 6bb. Namely, the force for performing clockwise rotation of the magnet 6ba and the force performing counterclockwise rotation of the magnet 6bb block each other. Since magnetic pole faces of the magnets 6ba and 6bb do not confront those of the second

stationary member 4, a force applied to the movable member 6 is reduced. Therefore, by employing the C-shaped second stationary member 4, a force applied to the movable member 6 in the rotational direction can be made larger than that of the E-shaped second stationary member 4.

[0046]

Then, operation of the first embodiment is described. It is supposed here that the movable member 6 is disposed at the above mentioned reference positions in the axial direction and the rotational direction and electric current is not flowing through the first coil 3 and the second coil 5. At this time, since the movable member 6 is in a balanced state shown in Fig. 5, the movable member 6 is at a standstill without undergoing any force both in the axial direction and in the rotational direction.

[0047]

If AC voltages of rectangular waves represented by curves VS and VR1 are, respectively, applied to the first coil 3 and the second coil 5 as shown in Fig. 8, AC flows through the first coil 3 and the second coil 5. Thus, the first coil 3 excites the magnetic path passing through the first stationary member 2, while the second coil 5 excites the magnetic path passing through the second stationary member 4. Hence, the movable member 6 undergoes the force oriented in the axial direction and the force oriented in the rotational direction as shown in Fig. 5. Phase of AC flowing through the first coil 3 and the second coil 5 changes according to motion of the movable member 6, the number of the coil, etc. but the movable member 6 is moved in the axial direction as shown by, for example, a curve DS of Fig. 8 by AC flowing through the first coil 3. On the other hand, in the phase shown in, for example, Fig. 8, the second coil 5 performs

counterclockwise rotation of the movable member 6 in an interval RL and clockwise rotation of the movable member 6 in an interval RR. Therefore, the movable member 6 reciprocates in the rotational direction at a period identical with that of the axial direction while reciprocating in the axial direction.

[0048]

Meanwhile, axial motion and rotational motion of the movable member 6 can be controlled independently of each other. Thus, if a frequency of an AC voltage applied to the second coil 3 is set twice that of an AC voltage applied to the first coil 3 as shown by a curve VR2 in Fig. 9, the movable member 6 can be reciprocated twice in the rotational direction while reciprocating in the axial direction.

[0049]

In the first embodiment, the force oriented in the axial direction is applied to the movable member 6 when the magnetic path flowing through the first stationary member 2 is excited by the first coil 3, while the force oriented in the rotational direction is applied to the movable member 6 when the magnetic path flowing through the second stationary member 4 is excited by the second coil 5. Thus, axial motion and rotational motion of the movable member 6 can be controlled independently of each other. As a result, it is possible to upgrade degree of freedom of operational control of the actuator in which the movable member 6 can be moved in two directions of the axial direction and the rotational direction without using a motion direction converting mechanism.

[0050]

Since masses of the magnets 6ba and 6bb of the movable member 6 are distributed symmetrically with respect to the rotational axis, inertia force

based on rotational motion of the movable member 6 is cancelled and thus, vibrations to be transmitted to the casing 1 can be reduced. Meanwhile, since the first stationary members 2 and the second stationary members 4 apply to the movable member 6 the force oriented in the axial direction and the force oriented in the rotational direction, respectively by using the magnetic poles disposed at opposite sides of the magnets 6ba and 6bb of the movable member 6, so that the movable member 6 can be moved with great force.

[0051]

Furthermore, if the first stationary member 2 is formed into the E-shaped configuration and the second stationary member 4 is formed into the C-shaped configuration such that the first stationary member 2 and the second stationary member 4 are disposed so as to intersect with each other orthogonally, an interval between the first stationary member 2 and the second stationary member 4 becomes large, so that a space for providing the first coil 3 and a space for providing the second coil 5 can be increased. Meanwhile, when the magnets 6ba and 6bb of the movable member 6 are positioned so as to confront the first stationary member 2, the magnetic pole portions of the first stationary member 2 are disposed at positions suitable for producing the force in the axial direction, so that leakage flux is lessened and the movable member 6 can be efficiently moved in the axial direction with great force. Meanwhile, when the magnets 6ba and 6bb are positioned so as to confront the two magnetic pole portions of the second stationary member 4, the magnetic pole portions of the second stationary member 4 are disposed at positions suitable for producing the force in the rotational direction, so that leakage flux is lessened and the movable member 6 can be efficiently moved in the rotational direction with great force.

[0052]

(Second embodiment)

Hereinafter, a second embodiment of the present invention directed to Claims 1 to 8 and 11 is described with reference to Fig. 10. The second embodiment is different from the first embodiment in shapes and relative position of the first stationary member 2 and the second stationary member 4. Other constructions of the second embodiment are the same as those of the first embodiment.

[0053]

As viewed in the axial direction, the magnetic pole portions of the first stationary member 2 and the second stationary member 4 are spaced a predetermined gap from a magnetic pole face formed by a cylindrical side face of the movable member 6. The magnetic pole portions of the second stationary member 4 are provided in the recesses of the E-shaped first stationary member 2, respectively. Therefore, as viewed in the axial direction, end portions of the magnetic pole portions of the first stationary member 2 and end portions of the magnetic pole portions of the second stationary member 4 form an overlap portion CP overlapping in three dimensions. Thus, a gap G is formed between the magnetic pole portions of the first stationary member 2.

[0054]

By the above described arrangement, since the first stationary member 2 and the second stationary member 4 secure a space for increasing an area in which the first stationary member 2 and the second stationary member 4 confront the movable member 6, the area can be increased, so that a large force can be applied to the movable member 6. Meanwhile, by providing the gap G,

magnetic reluctance of a magnetic path WC which does not contribute to application of a force to the movable member 6 and proceeds in, for example, the axial direction in the order of an N-pole of the first stationary member 2, the gap G, the second stationary member 4, the gap G and an S-pole of the first stationary member 2 is increased so as to reduce magnetic flux flowing through the magnetic path WC, so that a large force can be applied to the movable member 6. Here, a width of the gap G is designed in view of a width of a gap between the movable member 6 and the stationary members, etc.

[0055]

In the second embodiment, since the first stationary member 2 and the second stationary member 4 secure the space containing the area for confronting their magnetic pole portions with the movable member 6 as described above, the area for confronting their magnetic pole portions with the movable member 6 can be increased. Thus, since magnetic reluctance of the magnetic path between the first stationary member 2 and the second stationary member 4 increases, the magnetic flux which does not contribute to application of the force to the movable member 6 can be reduced. Therefore, a large force can be applied to the movable member 6 in the axial direction and in the rotational direction.

[0056]

(Third embodiment)

Hereinafter, a third embodiment of the present invention directed to Claims 1 to 6, 9 and 11 is described with reference to Fig. 11. The third embodiment is different from the first embodiment in shape of the movable member 6 and relative position of the movable member 6 and the first stationary

member 2. Other constructions of the third embodiment are the same as those of the first embodiment.

[0057]

The movable member 6 includes the cylindrical magnets having a thickness smaller than an axial width of the recesses of the E-shaped first stationary member 2 and a diameter of the cylindrical magnets is formed larger than a distance between the corresponding magnetic pole portions of a pair of the first stationary members 2 such that the cylindrical magnets are provided in between the E-shaped magnetic pole portions of the first stationary member 2. Hence, axial motion of the movable member 6 is restricted within the recesses of the first stationary member 2. Meanwhile, each of the two magnets 6ba and 6bb has opposite faces orthogonal to the axial direction and the movable member 6 is rotated such that an end portion of the faces of each of the magnets 6ba and 6bb traverses each of the recesses of the E-shaped first stationary member 2. Thus, since an area in which magnetic pole portions of the magnets 6ba and 6bb of the movable member 6 confront the magnetic pole portions of the first stationary member can be increased, the movable member 6 is moved in the axial direction with great force.

[0058]

In the third embodiment, since the area in which the magnetic pole portions of the magnets 6ba and 6bb of the movable member 6 confront the magnetic pole portions of the first stationary member 2 can be increased as described above, the movable member 6 can be moved in the axial direction with great force.

[0059]

(Fourth embodiment)

Hereinafter, a fourth embodiment of the present invention directed to Figs. 1 to 6, 10 and 11 is described with reference to Figs. 12 and 13. The fourth embodiment is different from the first embodiment in shape of the movable member 6. Other constructions of the fourth embodiment are the same as those of the first embodiment.

[0060]

The magnets 6ba and 6bb of the movable member 6 are formed into a cylindrical shape of an identical size such that not only opposed end faces of the magnets 6ba and 6bb are brought into contact with each other but other end faces of the magnets 6ba and 6bb remote from the opposed end faces are flush with axial opposite end faces of the first stationary member 2, respectively. The contacting opposed end faces of the magnets 6ba and 6bb are disposed at an axial center of the central magnetic pole portion of the E-shaped first stationary member 2.

[0061]

By the above described arrangement, a position where the other end faces of the magnets 6ba and 6bb are flush with the axial opposite end faces of the first stationary member 2, respectively presents a stable point. At this time, thrust characteristics are indicated in Fig. 13 by a curve FZ2 in which electric current does not flow through the coil, a curve FP2 in which electric current flows through the coil in a plus direction and a curve FM2 in which electric current flows through the coil in a minus direction. Namely, if the movable member 6 is displaced in the axial direction, the characteristics are such that a force for returning the movable member 6 in the reverse direction is generated. Therefore,

since the movable member 6 is operated as if the movable member 6 were coupled with a return spring, the movable member 6 can be reciprocated stably.

[0062]

In the fourth embodiment, the position where the other end faces of the magnets 6ba and 6bb are flush with the axial opposite end faces of the first stationary member 2, respectively presents the stable point as described above. Hence, as axial displacement of the movable member 6 becomes larger, larger force is applied to the movable member 6 in the direction opposite to that of the axial displacement, so that effect of the return spring can be gained.

[0063]

Meanwhile, the magnet portion 6b of the movable member 6 is formed by the two magnets held in contact with each other but the two magnets may be replaced by an integral part.

[0064]

(Fifth embodiment)

Hereinafter, a fifth embodiment of the present invention directed to Claims 1 to 6 and 11 is described with reference to Fig. 14. The fifth embodiment is different from the first embodiment in method of winding the first coil 3 around the first stationary member 2. Other constructions of the fifth embodiment are the same as those of the first embodiment.

[0065]

In contrast with the first embodiment in which the first coil 3 wound around the central magnetic pole portion of the E-shaped first stationary member 2 as shown in Fig. 14(a), the first coil 3 is dividedly wound around each of the opposite magnetic pole portions of the first stationary member 2. At this time,

these coils 3 are connected to each other such that the central magnetic pole portion and the opposite magnetic pole portions are excited to different magnetic poles, respectively. By winding the first coils 3 around the first stationary member 2 dividedly, effect of thickness of the wound first coil 3 is less than that of winding the first coil 3 around the single location, so that a space for winding the first coil 3 around the first stationary member 2 can be reduced. Meanwhile, as shown in Fig. 14(c), the first coil 3 can also be wound around each of the magnetic pole portions of the first stationary member 2 dividedly.

[0066]

In the fifth embodiment, since by winding the first coil 3 around the first stationary member 2 dividedly, effect of thickness of the wound first coil 3 is less than that of winding the first coil 3 around the single location as described above, the space for winding the first coil 3 around the first stationary member 2 can be reduced further.

[0067]

(Sixth embodiment)

Hereinafter, a sixth embodiment of the present invention directed to Claims 1 to 6 and 10 to 14 is described with reference to Fig. 15. This sixth embodiment is different from the fourth embodiment in provision of a resonant spring 8. Other constructions of the sixth embodiment are the same as those of the fourth embodiment.

[0068]

The resonant spring 8 is formed by a coiled spring and the coiled spring in a deflected state is provided between the casing 1 and each of the opposite ends of the movable member. Opposite ends of the resonant spring 8

are attached to the casing 1 and the movable member 6, respectively. Thus, the resonant spring 8 can serve as a spring for not only motion in the axial direction but motion in the rotational direction. Namely, the resonant spring 8 has both a function of an axial resonant spring 8a used for resonance in the axial direction and a function of a rotational resonant spring 8b used for resonance in the rotational direction.

[0069]

Therefore, when the first coil 3 is subjected to an AC voltage for excitation at a frequency close to a resonant frequency determined by an axial spring constant of the resonant spring 8, i.e., a spring constant of the axial resonant spring 8a and a mass of the movable member 6, the movable member 6 is efficiently reciprocated in the axial direction on the basis of a resonance phenomenon. Meanwhile, when the second coil 5 is subjected to an AC voltage for excitation at a frequency close to a resonant frequency determined by a rotational spring constant of the resonant spring 8, i.e., a spring constant of the rotational resonant spring 8b and a moment of inertia of the movable member 6, the movable member 6 is efficiently reciprocated in the rotational direction on the basis of a resonance phenomenon. Here, the frequency of the inputted AC voltage is set to be close to the resonant frequency because an actual resonant frequency deviates slightly from a resonant frequency of a motion system due to influence exerted by an electric circuit for applying the AC voltage to the coil.

[0070]

In the sixth embodiment, the single resonant spring 8 has the functions of the axial resonant spring 8a and the rotational resonant spring 8b as described above. Thus, when the first coil 3 is subjected to the AC voltage at the

frequency close to the resonant frequency determined by the mass of the movable member 6 and the spring constant of the axial resonant spring 8a, the movable member 6 can be efficiently reciprocated in the axial direction at a large amplitude on the basis of the resonance phenomenon. Meanwhile, when the second coil 5 is subjected to the AC voltage at the frequency close to the resonant frequency determined by the moment of inertia of the movable member 6 and the spring constant of the rotational resonant spring 8b, the movable member 6 can be efficiently reciprocated in the rotational direction at a large amplitude on the basis of the resonance phenomenon. Meanwhile, since the axial resonant spring 8a and the rotational resonant spring 8b form the single resonant spring 8, a space for providing the resonant spring 8 can be lessened.

[0071]

Meanwhile, in the foregoing description, the single resonant spring 8 has the functions of the axial resonant spring 8a and the rotational resonant spring 8b. However, the sixth embodiment is not limited to this arrangement but the axial resonant spring 8a and the rotational resonant spring 8b may also be provided separately. To this end, a leaf spring and a spiral spring, for example, may be used as the axial resonant spring 8a and the rotational resonant spring 8b, respectively.

[0072]

Meanwhile, if one of the coiled spring as the axial resonant spring 8a and the coiled spring as the rotational resonant spring is inserted into the other of the coiled springs so as to be combined therewith, a space for providing the resonant spring 8 can be reduced.

[0073]

Meanwhile, in the foregoing description, the magnets of the driving force generator 6b of the movable member 6 are symmetrical with respect to the rotational axis, while a pair of the first stationary member 2 and a pair of the second stationary members 4 are provided symmetrically with respect to the axis so as to be excited in the antiphase mode. However, the present invention is not limited to this arrangement but the single first stationary member 2 and the single second stationary member 4 may be provided such that only a magnetic pole at one side of the magnet is used.

[0074]

Meanwhile, in the foregoing description, the driving force generator 6b includes the two magnets. However, if the first stationary member 2 includes one magnetic pole portion or two magnetic pole portions in, for example, a C-shaped first stationary member 2 having two magnetic pole portions arranged in the axial direction and the second stationary member 4 includes one magnetic pole portion, the single magnet may be employed and the movable member 6 can be moved in the axial direction and the rotational direction.

[0075]

[Effects of the Invention]

In the invention of Claim 1, since the first stationary imparts to the movable member the force oriented in the axial direction when the first coil excites the magnetic path passing through the first stationary member, while the second stationary member imparts to the movable member the force oriented in the rotational direction when the second coil excites the magnetic path passing through the second stationary member, motions of the movable member in the axial direction and in the rotational direction can be controlled independently of

each other. As a result, it is possible to upgrade degree of freedom of operational control of the actuator which is capable of moving in two directions of the axial direction and the rotational direction without using a motion direction converting mechanism.

[0076]

In the invention of Claim 2, since mass of the magnet of the movable member is distributed symmetrically with respect to the rotational axis, inertia force based on motion of the movable member in the rotational direction is cancelled, so that vibrations transmitted to the casing can be lessened in addition of the effect of Claim 1.

[0077]

In the invention of Claim 3, since the first and second stationary members impart, by using opposite magnetic poles of the magnet of the movable member, to the movable members the force oriented in the axial direction and the force oriented in the rotational direction, the movable member can be moved with great force in addition to the effect of Claim 1 or 2.

[0078]

In the invention of Claim 4, since an interval between the first and second stationary members becomes large, a space for providing the first and second coils can be enlarged in addition to the effects of Claim 3.

[0079]

In the invention of Claim 5, when the two magnets are disposed so as to confront the first stationary member, the magnetic pole portions of the first stationary member are disposed at positions suitable for producing a force oriented in the axial direction. Thus, leakage flux is lessened and the movable

member can be efficiently moved in the axial direction with great force in addition to the effects of Claims 1 to 4.

[0080]

In the invention of Claim 6, when the two magnets are disposed so as to confront the two magnetic pole portions of the second stationary member, the magnetic pole portions of the second stationary member are disposed at positions suitable for producing a force oriented in the rotational direction. Thus, leakage flux is lessened and the movable member can be efficiently moved in the rotational direction with great force in addition to the effects of Claim 5.

[0081]

In the invention of Claim 7, since a space covering an area for confronting the first stationary member with the movable member and a space covering an area for confronting the second stationary member with the movable member are secured, the area for confronting the first stationary member with the movable member and the area for confronting the second stationary member with the movable member can be increased, so that a large force can be applied to the movable member in addition to the effects of Claim 6.

[0082]

In the invention of Claim 8, since a magnetic reluctance of a magnetic path between the first stationary member and the second stationary member is increased, a magnetic flux which does not contribute to application of a force to the movable member can be reduced in addition to the effects of Claim 7.

[0083]

In the invention of Claim 9, since an area for confronting a magnetic pole portion of each of the magnets with each of the magnetic pole portions of the

first stationary member can be increased, the movable member can be moved in the axial direction with great force in addition to the effects of Claim 6.

[0084]

In the invention of Claim 10, a position where the other end faces of the magnets are flush with the axial opposite end faces of the first stationary member presents a stable point. Thus, as axial displacement of the movable member becomes larger, a larger force is applied to the movable member in a direction opposite to that of the axial displacement, so that effect of a return spring can be gained in addition to the effects of Claim 6.

[0085]

In the invention of Claim 11, by dividing the coils, an influence of a thickness of the wound coils is lessened in comparison with a case in which the coils are wound around one location, so that a space for winding the coils can be reduced in addition to the effects of Claim 6.

[0086]

In the invention of Claim 12, when an AC voltage is applied to the first coil at a frequency close to a resonant frequency determined by a mass of the movable member and a spring constant of the axial resonant spring, the movable member can be efficiently reciprocated in the axial direction at a large amplitude on the basis of a resonance phenomenon in addition to the effects of Claims 1 to 11.

[0087]

In the invention of Claim 13, when an AC voltage is applied to the second coil at a frequency close to a resonant frequency determined by a moment of inertia of the movable member and a spring constant of the rotational resonant

spring, the movable member can be efficiently reciprocated in the rotational direction at a large amplitude on the basis of a resonance phenomenon in addition to the effects of Claim 12.

[0088]

In the invention of Claim 14, since the axial resonant spring and the rotational resonant spring are formed by the single spring member, a space for providing the axial resonant spring and the rotational resonant spring can be reduced in addition to the effects of Claim 13.

BRIEF DESCRIPTION OF THE DRAWINGS:

Fig. 1 is a partly sectional perspective view illustrating a first embodiment.

Fig. 2 is a sectional view taken along the line A-A in Fig. 1.

Fig. 3 is a sectional view taken along the line B-B in Fig. 1.

Fig. 4 is a sectional view illustrating the first embodiment and includes Fig. 4(a) of its section C-C and Fig. 4(b) of its section D-D.

Fig. 5 is a characteristic diagram of the first embodiment and includes Fig. 5(a) of characteristics between axial displacement and thrust and Fig. 5(b) of characteristics between rotational angle and torque.

Fig. 6 is a sectional view taken along the line B-B, in which a second stationary member of the first embodiment is replaced by an E-shaped one.

Fig. 7 is a sectional view of the E-shaped second stationary member and includes Fig. 7(a) of its section E-E and Fig. 7(b) of its section F-F.

Fig. 8 is a waveform diagram showing operation of the first embodiment.

Fig. 9 is a waveform diagram showing another operation of the first

embodiment.

Fig. 10 shows a main portion of a second embodiment and includes Fig. 10(a) of its perspective view and Fig. 10(b) of its top plan view.

Fig. 11 is a sectional view illustrating a third embodiment and corresponding to the section A-A in Fig. 1.

Fig. 12 is a sectional view illustrating a fourth embodiment and corresponding to the section A-A in Fig. 1.

Fig. 13 is a characteristic diagram showing characteristics between axial displacement and thrust in the fourth embodiment.

Fig. 14 is a fragmentary sectional view showing a first stationary member and a first coil in a fifth embodiment.

Fig. 15 is a sectional view illustrating a sixth embodiment and corresponding to the section A-A in Fig. 1.

[Reference numerals]

1: Casing

1a: Housing portion

1b: Bearing portion

2: First stationary member

3: First coil

4: Second stationary member

5: Second coil

6: Movable member

6a: Shaft

6b: Driving force generator

6ba: Magnet

6bb: Magnet

8: Resonant spring

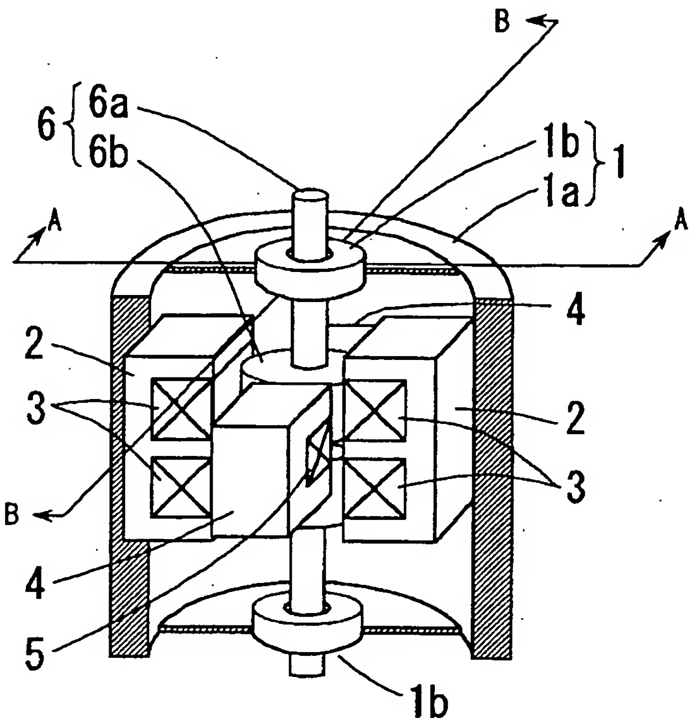
8a: Axial resonant spring

8b: Rotational resonant spring

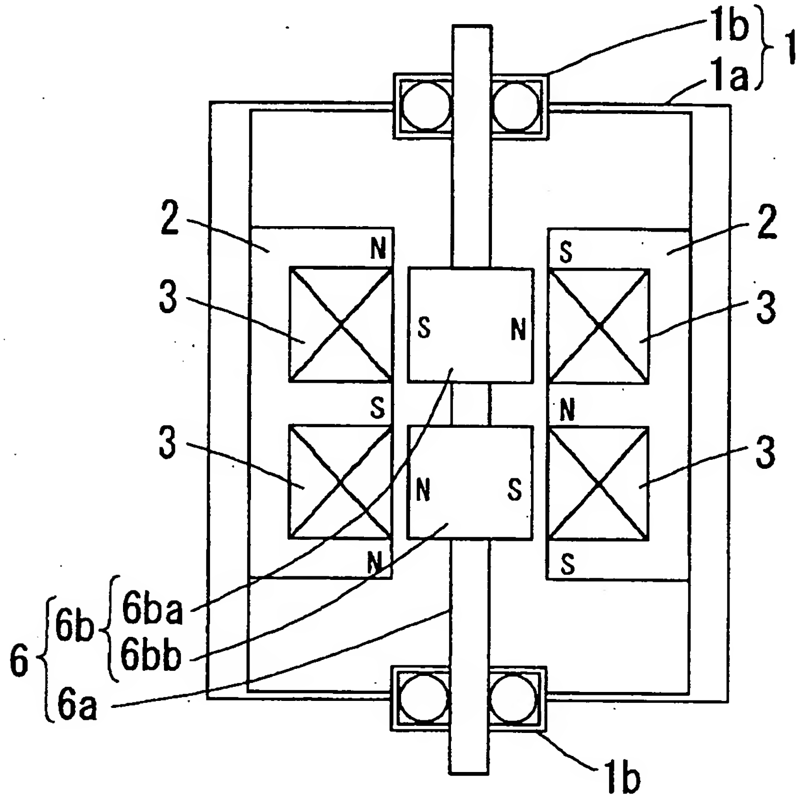
G: Gap

【書類名】　図面　Document name: Drawings

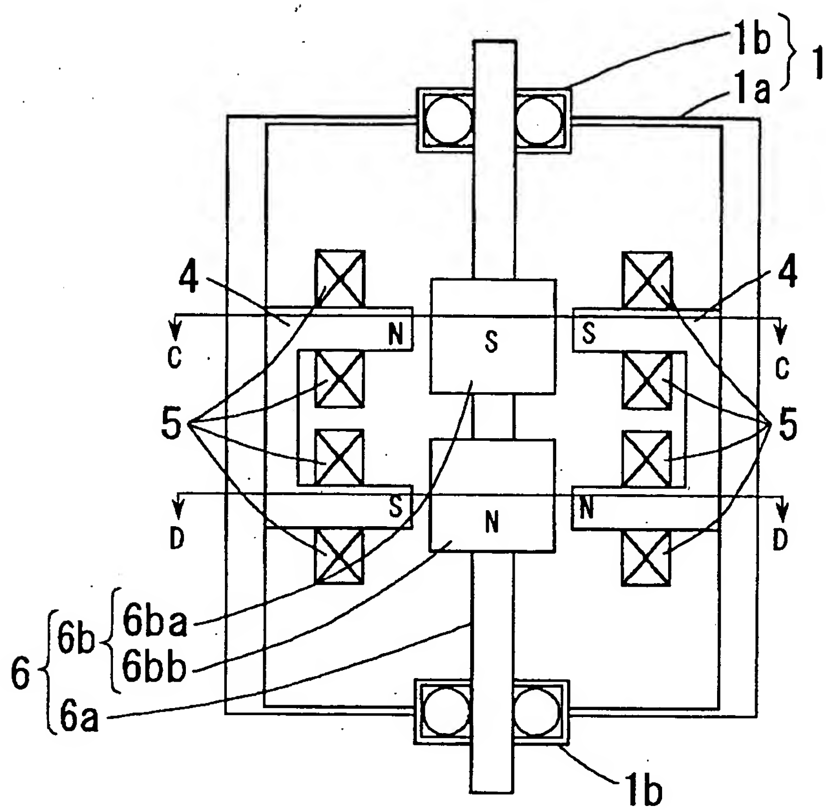
【図１】
Fig. 1



【図２】
Fig. 2

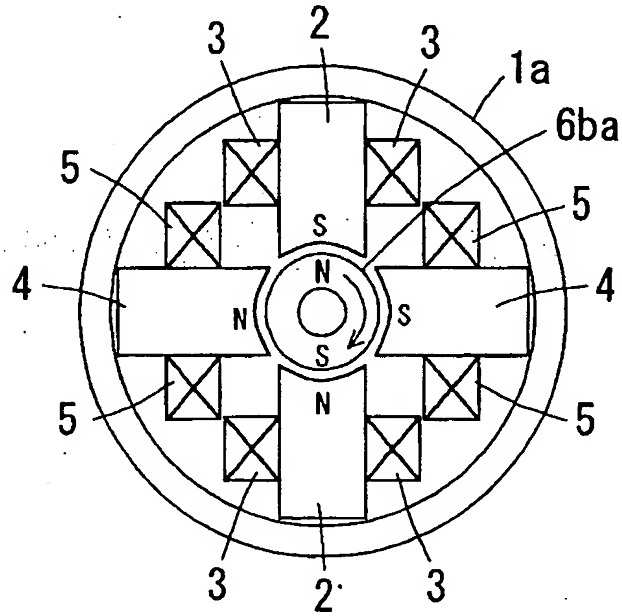


【図３】
Fig. 3

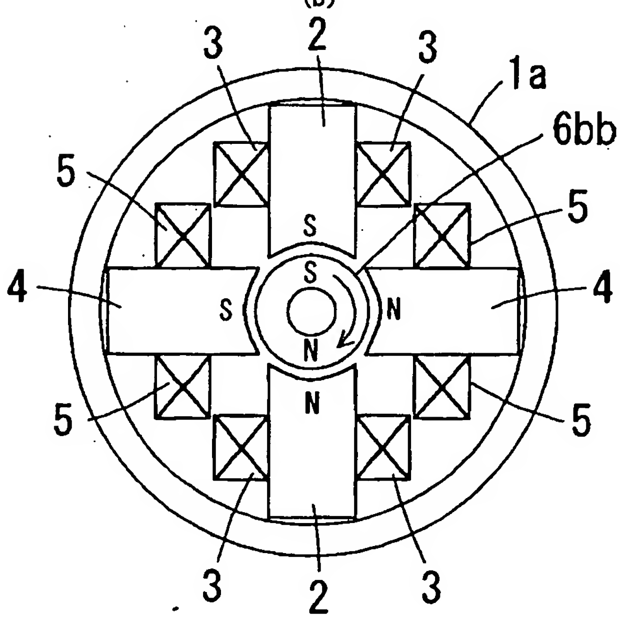


【図４】
Fig. 4

(a)

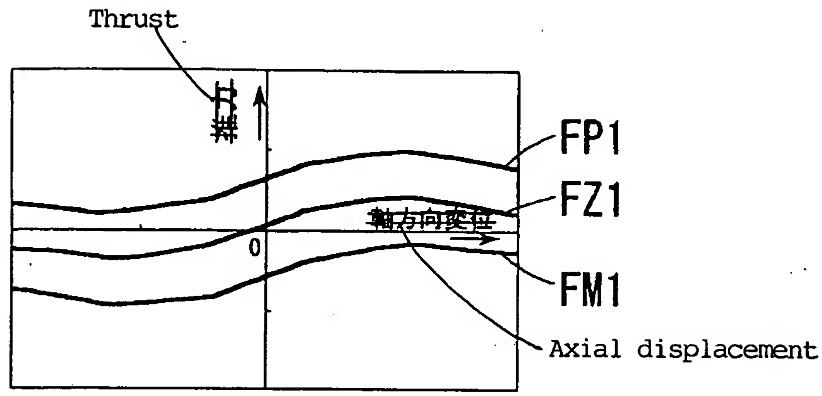


(b)

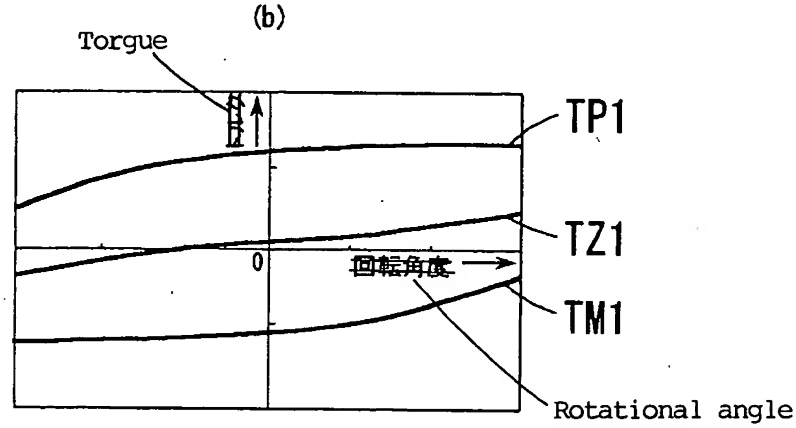


【図５】
Fig. 5

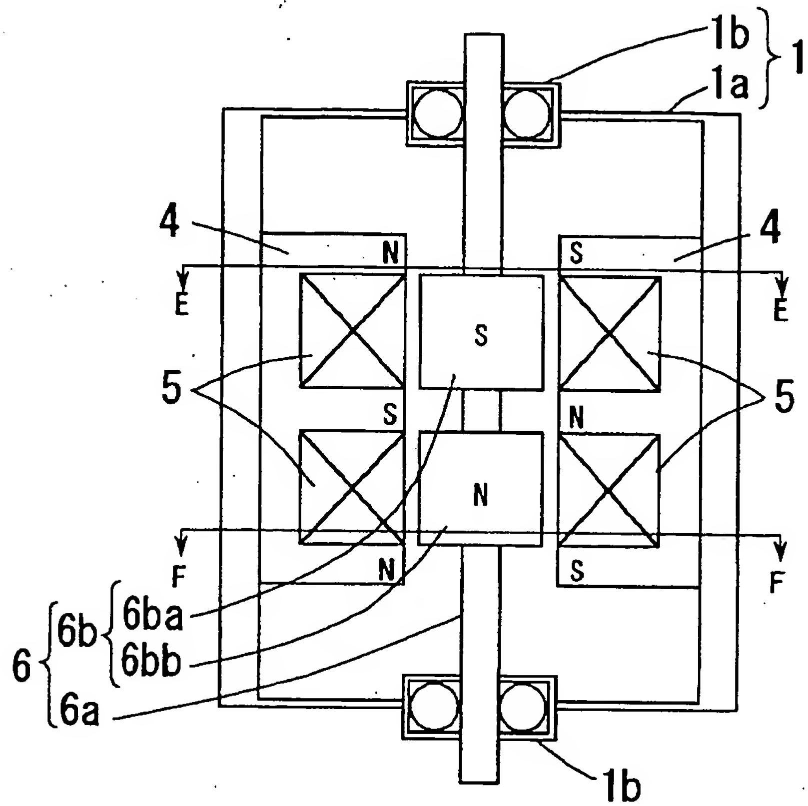
(a)


Thrust
推力
FP1
FZ1
軸方向変位
0
FM1
Axial displacement

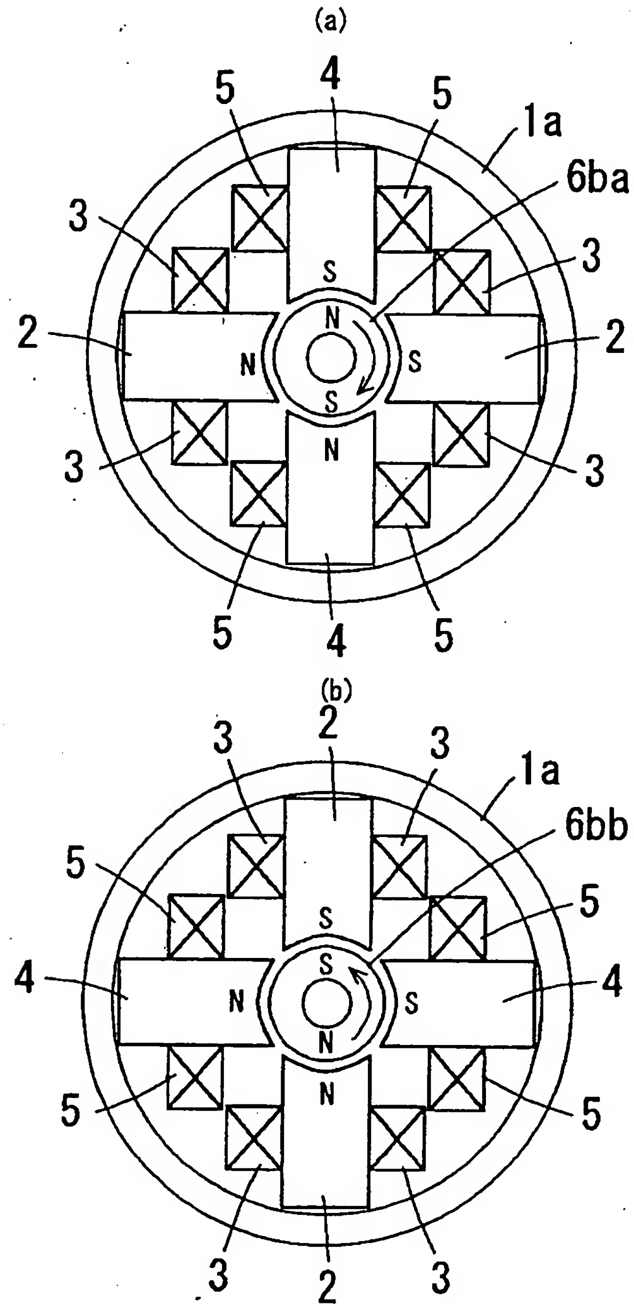
(b)


Torgue
トルク
TP1
TZ1
0
回転角度
TM1
Rotational angle

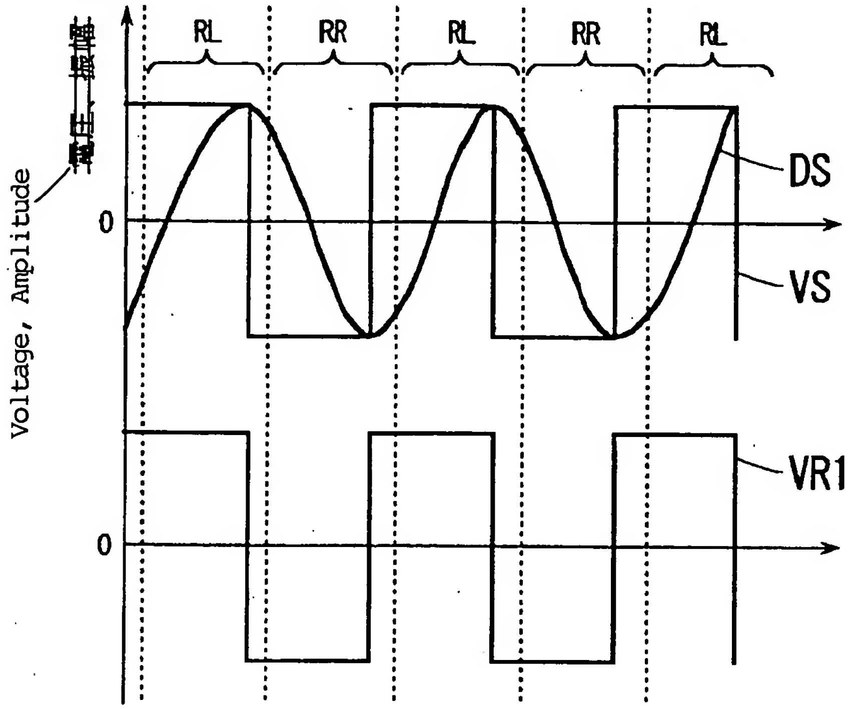
【図６】
Fig. 6



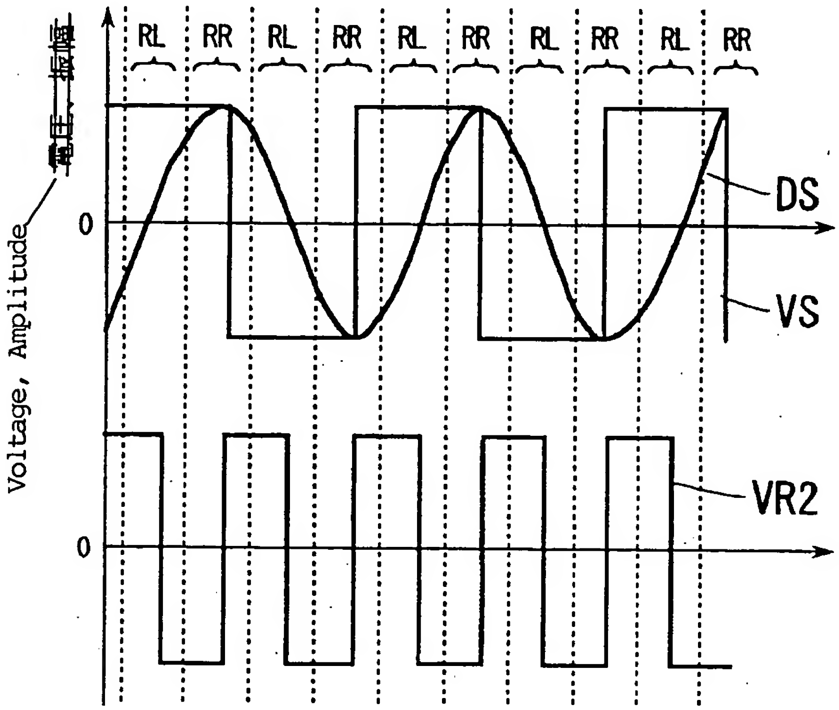
【図７】
Fig. 7



【図８】
Fig. 8

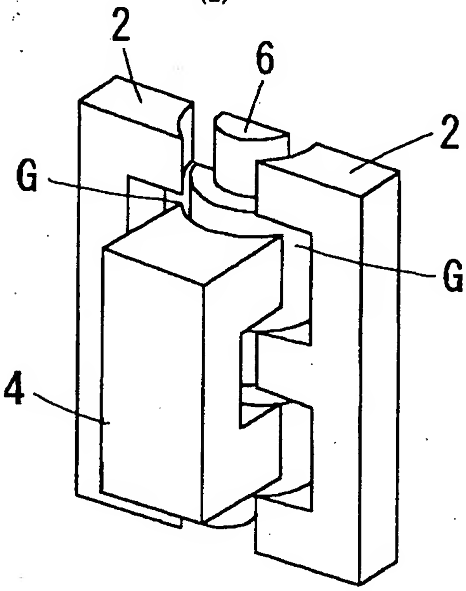


【図９】
Fig. 9

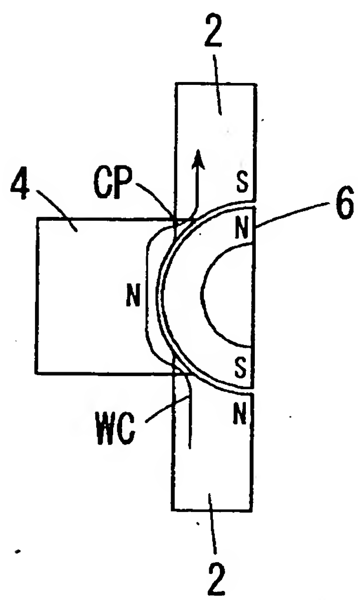


【図１０】
Fig. 10

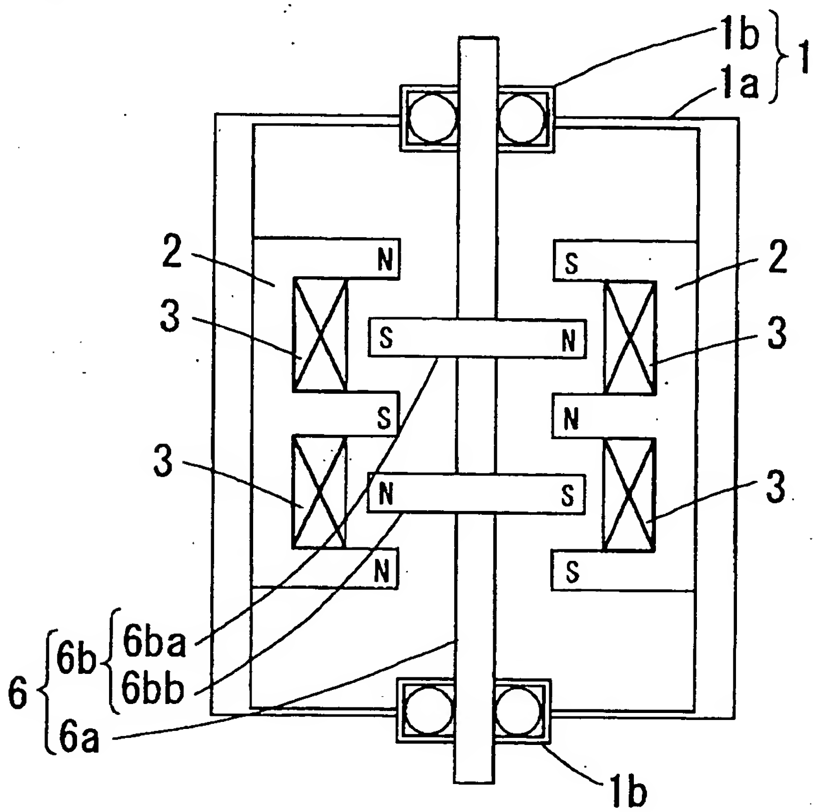
(a)



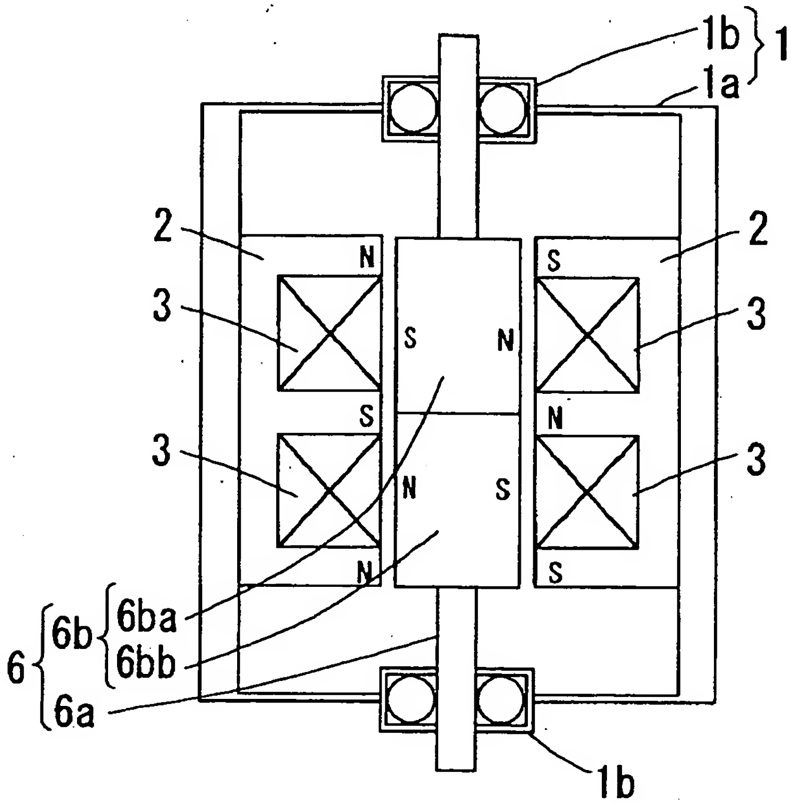
(b)



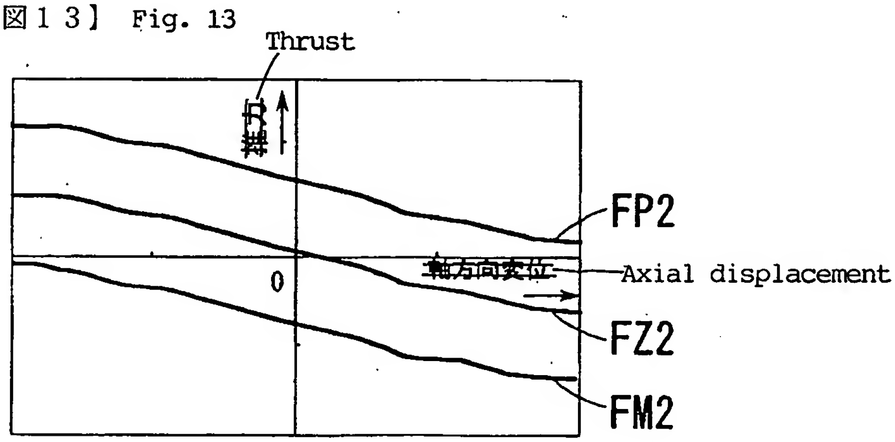
【図１１】
Fig. 11



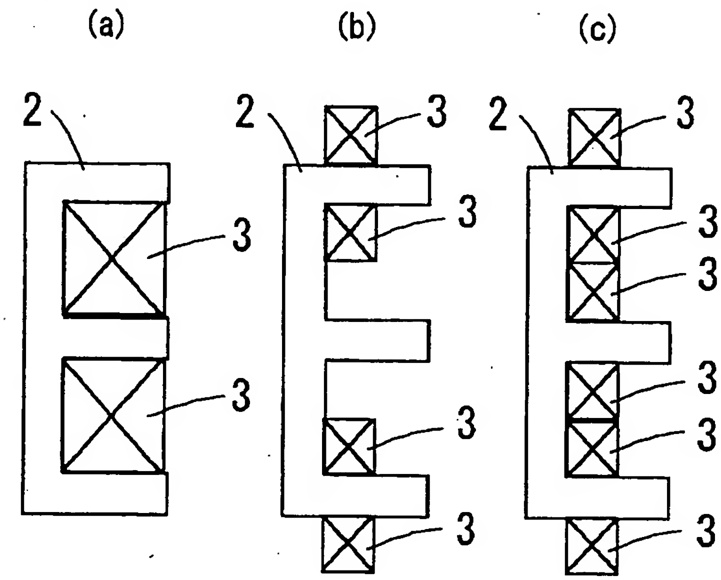
【図１２】
Fig. 12



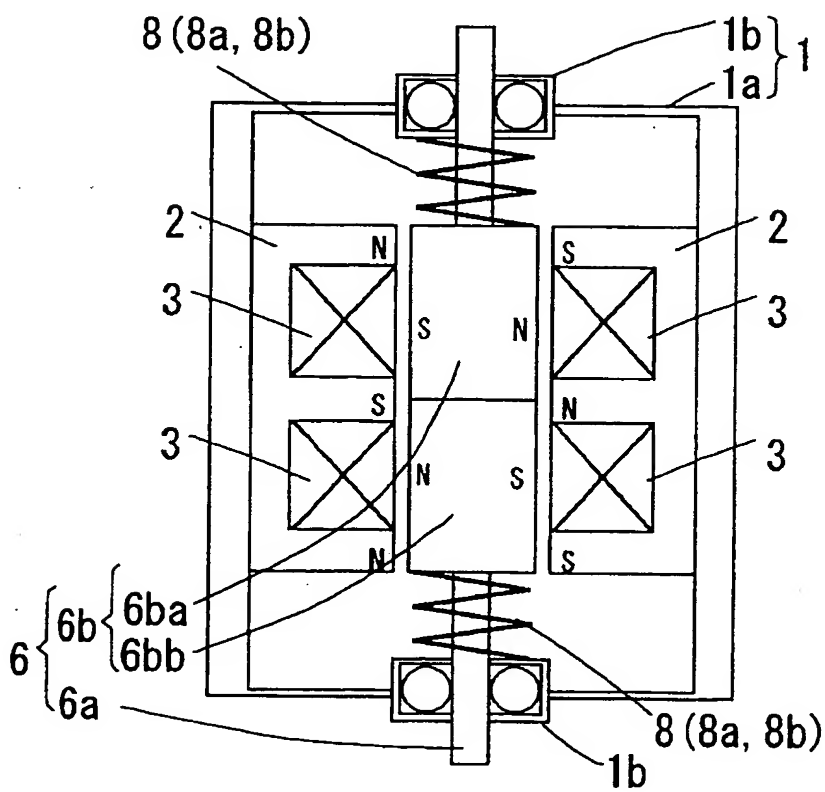
【図１３】　Fig. 13



【図１４】
Fig. 14



【図１５】
Fig. 15



Document Name: Abstract

Abstract:

[Object]

In an actuator which is capable of moving in two directions of an axial direction and a rotational direction without using a motion direction converting mechanism, degree of freedom of operational control is upgraded.

[Solution Means]

An actuator of the present invention includes a stationary member which has a coil, a casing for accommodating the stationary member and a movable member which has a shaft and is supported by the casing so as to be moved in an axial direction of the shaft and in a rotational direction having the shaft as its rotational axis. Electric current is caused to flow through the coil so as to move the movable member in the axial direction and in the rotational direction. The movable member has a magnet having a magnetization direction substantially orthogonal to the axial direction. The stationary member includes a first stationary member for imparting to the movable member by the magnet a force oriented in the axial direction and a second stationary member for imparting to the movable member by the magnet a force oriented in the rotational direction. The coil includes a first coil for exciting a magnetic path passing through the first stationary member and a second coil for exciting a magnetic path passing through the second stationary member.

[Selected Drawing]

Fig. 1

Applicant Record

Identification No.: 000005832

1. Date of Registration: August 30, 1990 (newly recorded)

   Address: 1048, Oaza-Kadoma, Kadoma-shi, OSAKA

   Name: Matsushita Electric Works, Ltd.